

## PCFB GASIFICATION OF BIOMASS

ANDERS L. HALLGREN, INGEMAR BJERLE,  
LARS A. CHAMBERT  
University of Lund  
Chemical Center  
Dept. of Chem.Eng. II  
Box 124, S-221 00 Lund  
Sweden

**Keywords:** pressurized circulated fluidized bed biomass gasification; hot gas filtering; hot gas alkali removal

### INTRODUCTION

Gasification technology is and has been widely used in different ways of commercial fuel gas production. Coal gasification technology has shown to have potential also in biomass gasification although it must be kept in mind that coal and biomass show quite different behavior in thermochemical processes. The technology has been applied to biomass gasification and numerous research efforts are referred to in the literature. These represent in many ways a firm theoretical base [1,2].

Nevertheless, additional comprehensive information is needed for taking the technology of pressurized biomass gasification into industrial scale applications. However, the real commercial impact in power generation is yet to be seen mainly because of perhaps immature biomass pretreatment and conversion technology, lacking hot gas cleaning solutions and of course depending on relatively low oilprices. A successful commercial development of the technology is needed and how fast this is going to take place is crucial for the introduction of biomass based power production.

#### Research activities in the United States

Considerable efforts and substantial resources have been invested in studying pressurized gasification. A small selection of the recent efforts is presented below [3,4].

The Institute of Gas Technology (IGT) in Chicago (IL) has been conducting research with an oxygenblown, fluidized-bed gasification reactor designed to operate at pressures up to 3.5 MPa. IGT has carried out a comprehensive test matrix with the Renugas process development unit with funds from the U.S. Department of Energy (DoE). These tests have been completed to determine the effects of various process variables in order to obtain parametric information for process optimization with refuse derived fuels (RDF) and other biomass feedstocks.

On the Maui island of Hawaii the Pacific International Center for High Technology Research (PICHTR), Hawaii Natural Energy Institute of the University of Hawaii, Hawaiian Commercial Sugar Company, The Ralph M. Parson Engineering Company, and IGT are planning a demo-scale plant for biomass (bagasse) gasification. The start of operation is scheduled for the second half of 1993 and the experimental program will be supported by the US Department of Energy. The IGT Renugas process is going to be applied, i.e. the pressurized air-blown fluidized bed gasifier. Apart from the main fuel bagasse other biomass and wastes such as eucalyptus wood chips, RDF, and agricultural wastes will be used as well.

The University of Missouri-Rolla has been investigating the technical feasibility of using a metal fired-tub heat-exchanger to provide heat for a fluidized-bed gasifier. This concept allows the production of medium-energy gas or synthesis gas without the use of oxygen. The gasifier is a stainless steel reactor fitted with an internal heat exchanger bundle consisting of thirty stainless steel U-tubes. Hot combustion flue gases, which could be produced by burning a portion of the product gas or other fuels such as char, are passed through the heat exchanger. Extensive series have been conducted in order to determine the effect of various process variables. Wood feed rates ranged from 45 kg/h to 180 kg/h producing a product gas with a higher heating value ranging from 14.6 to 21.6 MJ/Nm<sup>3</sup>.

Battelle-Columbus Laboratories (BCL), Columbus (Ohio) has conducted research on a medium-energy gasification process which involved an indirectly heated dual fluidized bed gasifier by circulating low density, incandescent sand to the gasifier. Entrained sand and any non-reacted char leaving the gasifier are separated from the gas product in a cyclone. The char and sand are fed into a fluidized-bed, air-fired, combustor where the char and supplementary fuel are burned. The BCL gasification process is capable of operations at temperatures up to 870°C and pressures slightly above atmospheric. The gasifier has been tested with a number of biomass feedstocks including hard and soft wood chips, sawdust, hogged fuel and bark strips at wood feed rates as high as 960 kg/h. The gas product higher heating value has been ranging from 16.0 to 19.1 MJ/Nm<sup>3</sup> and the carbon conversion to gas in the gasification reactor varied from 50 to over 90 % for wood containing 3-34 % moisture.

### **Research activities in Europe**

A commercial application of gasifiers developed in Finland is the A. Ahlström Oy PYROFLOW circulating fluidized-bed gasifier. A maximum thermal output of 35 MW is accomplished using not only waste wood as the main fuel but also peat is a well-suited feedstock. The PYROFLOW gasifier consists of a refractory-lined cylindrical vessel and a refractory-lined cyclone. A fluidized-bed of hot sand is operated in a circulating mode where dry waste wood is entering the bed through the side of the reactor.

The German company Lurgi GmbH has been involved in developing and designing commercial gasifiers applicable for various feedstocks ranging from coal to biomass, wastes and RDF. The circulating fluidized-bed gasification system is commercially available for the production of low-energy gas. The gas produced is suitable for a number of processes and particular interesting for the paper and pulp industry, where sufficient bark and wood-waste are produced without costly transportation and distribution overheads to partly substitute oil and gas.

Besides the applied biomass gasification technology, basic research has been reported in the literature from different places in Europe. However, the topics covers a broad scientific spectrum which is sometimes difficult to overview. Research groups at VTT in connection with universities in Finland represent a forward position in this field and additionally the University of Saragossa (Spain) should be mentioned in this context. Lately here basic research was successfully conducted in catalytic steam gasification of biomass and wastes sponsored by the governmental funds.

### **Research activities in Sweden**

The biomass gasifiers built in Sweden so far have been, with few exception, atmospheric updraft/ downdraft or fluidized bed gasifiers for the production of burnable gases for district heating systems and the paper pulp industry. One of the exceptions is the Studsvik MINO-plant which was planned for the production of synthesis gas from wood through pressurized oxygen gasification. Comprehensive research efforts were made with the MINO plant and gave the Studsvik Energy, Thermal Processes Laboratory a leading position in gasification technology [5].

During the last years the power industry in Sweden has shown a growing interest in the gasification technology and particularly in biomass gasification. Through combined cycle applications good possibilities are supposed to be given in producing environmentally favourable power at high efficiency. In the light of 10 GW nuclear power generation in Sweden phasing out after the year 2010, it has been shown that Sweden has a potential of 33-53 TWh/year of electricity from biomass based gas turbine systems.

Taken in connection with Sweden's traditionally genuine knowledge in the field of thermochemical processing and particularly in the gasification technology, abundant opportunities should be available for successfully implementing biomass based power generation.

### **The PCFB biofuel gasifier at Lund Institute of Technology (LIT)**

The pressurized gasifier is intended to be a small flexible test rig which will offer adequate scientific results and constitute the link between lab-scale developments and industrial scale application. The pilot plant will to a certain degree be operated parallel to the Sydkraft biomass gasifier at Värnamo for evaluation and confirmation of the test results. The gasifier at LIT is constructed as a circulating

fluidized bed and the intentions are to study gasification of different biomass feedstocks at pressures up to 2.5 MPa and at temperatures between 600 - 1050°C.

The objective of the test program is to investigate the influences of the process parameters on each other and on the product distribution and composition. This will be done in as realistic circumstances as possible regarding pressure intervals, temperature and residence time intervals. In addition to studying the gasification process as such, investigations will be made regarding finishing treatments of the gas products at elevated temperatures and pressures. Examples of such treatments will be dust separation at high temperatures, desulfurization, tar cracking, catalytic ammonium dissociation, and hot gas alkali removal.

## APPARATUS

The equipment which is going to be used can be characterized as a process development unit (PDU). The PDU consist of four main parts; feeder, circulating fluidized bed (CFB), hot gas filter, and a reactor for catalytic treatment of dust free gas. The warm parts, i.e. the gasification reactor, the hot gas filter, and the catalytic reactor are concentrically placed inside an outer pressure vessel consisting of three vertical tubes of 0.5 m in diameter. The gas pressure inside these tubes is suppose to balance the process gas pressure. The pressure vessel also contains electric heating elements and insulation. A schematic diagram of the apparatus is shown in Figure 1.

### The feeding system

A well defined portion of the feeded biomass is transported with screws into a pressure chamber where the feeded material together with the gas are compressed by means of a hydraulic piston. From this chamber the biomass is screwed into the reactor inlet. This setup will demonstrate batch compression followed by continuous feeding into the reactor. Similar technical design has scarcely been seen reported in the literature or in studying patents, hence, the feeder construction might offer novel solutions in pressurized feeding systems.

### The gasifier

The gasifier is constructed as a circulating fluidized bed (CFB) gasifier with options to operate it as a bubbling bed gasifier. Great attention has been paid to give the experimental setup a broad range of flexibility for modifications. The reactor will have a diameter of 40.9 mm and an approx. height of 3 meter. This makes it possible to operate the CFB at fluidizing velocities and residence times that are comparable with those of industrial scale applications.

Flow conditions typical to CFB with small diameters have been reported in the literature [6]. A large amount of basic work regarding analyses of flow dynamics have been made with small scale equipment at atmospheric pressure and at various temperatures

Figure 3 shows the primary range of operation at 950 °C and at the pressure interval 0.4 - 2.0 MPa. Calculations have been done in order to find the influences of various fluidization velocities on the total gas production and fuel/air consumption. As can be noted in the diagram, the calculated maximum gas production is 42.24 Nm<sup>3</sup>/h at an air and fuel feed of 22.78 Nm<sup>3</sup>/h and 18 kg/h respectively.

A fluidization velocity of 1.0 m/s is the calculated minimum velocity in order to establish reasonable fluidization in the gasifier of diameter 40.9 millimeter. Accordingly, the maximum calculated fluidization velocity is 2.0 m/s in the pressure interval mentioned above.

The reactor consist of an inner and an outer tube with an annular space in between. The feed including bed material is introduced directly into the inner gasifier. Solid material will be separated from the gas phase with a low pressure axial cyclone at the top of the reactor. The separated solid materials are forced down through the annular space between the inner and outer reactor tube. At the bottom, material re-introduction into the riser at minimum acceleration losses and increased circulation is possible due to the design of the gas inlet distributor. The material recirculation is supposed to be governed by the height of the material in the return tube. High transport density and good mixing of the feed material and the separated solid materials are wanted in order to insure

gasification and gas quality. To demonstrate the function of these parts will probably show major practical significance in industrial scale applications.

#### **The hot gas filter**

Before the hot gas from the gasifier enters the filter element is cooled down to a temperature between 300-800°C depending on given circumstances. The gas is cooled by letting it pass a spiral shaped tube heat exchanger containing water at 2.0 MPa and 212°C.

The hot gas filter element consists of a sintered granular ceramic material. The filter is 1 meter long and have outer diameter of 60 mm and is designed as a single conventional industrial filter. The potential of the filter will be tested with respect to the function within a broad temperature interval for the optimization of future plants gas turbine inlet gas temperature.

#### **The catalytic reactor**

The catalytic reactor will be used for investigations concerning adsorption of alkali/trace metal elements, tar cracking, ammonia reduction, and  $H_2S$ . The reactor is of a downdraft type and consists of a stainless steel tube filled with the catalytic material. As for the gasifier and the hot gas filter, the catalytic bed reactor is concentrically placed inside an outer pressure vessel containing electric heat elements for heating up to approx. 1000°C.

## **EXPERIMENTAL**

### **Background**

Pyrolysis, thermal dissociation of an organic material in an oxidizing free atmosphere, is a thermal precursor to gasification. Gasification of solid materials is normally regarded as the combination of pyrolysis followed by heterogeneous and homogenous chemical reactions of chars, tars, and primary formed gaseous components.

In pure pyrolysis sufficient energy must be added for the conversion while in gasification adequate or at least part of the energy required for the reactions is internally produced mainly through oxidation of the pyrolysis products. Consequently, additional indirect heating can be kept at a minimum and sub-stoichiometric amounts of air, oxygen, and water vapor produce burnable gaseous products.

Through varying different parameters, e.g. temperature, pressure, and material residence time, the gasification reactions can be influenced in the desired direction that establish different spectra of the gas product composition. The equilibrium composition of the gas product for an adiabatic air/biomass conversion at different air to fuel ratios is indicated in Figure 4.

### **The experimental program**

Sawdust from wood and forest wastes in the first phase of the experimental program. Possibly other feedstocks such as RDF and agricultural wastes will be taken into account as feedstocks in future research programs.

A complete survey of the gasification products, including closing material balances, as well as scientific adequate gasification investigations are judged possible. The basic properties of the reactor will be studied including monitoring the flexibility influenced by different process conditions. In addition to general gasification studies the experimental program, based on two years, will focus on the following subjects:

- influences from the inherent moisture and the particle size distribution of the solid biofuel on product distribution and composition
- qualitative/quantitative analyses of the distribution of alkali/trace element metals in the gasification products
- influences from dolomite and other additives in the bed material
- tar and ammonia cracking as a function of the type catalysts.

Apart from the experimental program, verifications of dynamic modelling work of the reactor function will be carried out.

### SUMMARY

A pilot plant biomass PCFB-gasifier is being installed at the Chemical Center in Lund. The official project start-up was in February 1992 after a one-year extensive feasibility study with involvement's from design consultants and Sydkraft AB. However, the financial issue wasn't completely solved until late April 1992 which delayed the actual project start-up to the beginning of June 1992.

The purpose of the project is to establish realistic conditions for thermal gasification of biofuel and gas cleaning, and to study the various parameters involved in the process and how they influence each other.

#### Project status May 1993

A first version of a comprehensive literature survey has been concluded. This survey will be published and available through Nutek.

After a very busy investment period we are now escalating our efforts in assembling the pilot plant. A first pressurized test series with the biofuel feeding system has been successfully completed. Fluidization and feeding tests will be continued during the summer of 1993. Due to problems involved with the delivery of certain parts and materials, the experimental program start-up is delayed. The first phase of the experimental program will be implemented during the second half of 1993 and 1994.

### ACKNOWLEDGMENTS

This project is financially supported by the National Board for Industrial and Technical Development (NUTEK), Sydkraft AB, and the Swedish Energy Development Corporation (SWEDCO).

### REFERENCES

1. Rensfelt, E., "Practical Achievements in Biomass Gasification" paper presented at BioEnergy 84, June 18-21 1984, Gothenburg, Sweden.
2. Bridgewater, A.V., "An overview of thermochemical biomass conversion technologies", in Wood: fuel for thought. Proceedings of the conference held at Bristol (UK) 23-25 Oct. 1991.
3. Schiefelbein, G. F., "Biomass Thermal Gasification Research : Recent Results from the United States DOE's Research Program", Biomass 19 (1989) 145-159.
4. Trenka, A.R, Kinoshita, C.M., Takahashi, P.K., Phillips, V.D., Caldwell, C., Kwok, R., Onishak, M., Babu, S.P., "Demonstration plant for pressurized gasification of biomass feedstocks". 15th Annual Conference on Energy from Biomass and Wastes, Washington DC, March 25-29 1991.
5. Rensfelt, E., Waldheim, L., Blackadder, W.H., "Gasification research and development 1980-1990 by Studsvik", internal report STUDSVIK-EP--91/5, April 30, 1991.
6. Mori, S., et al, "Turbulent fluidization phenomena", Nagoya Inst. of Technology, Showa, Nagoya; Mitsubishi Gas Chemical Co Ltd, Matsuhama, Niigata; CFB Conference II, Compiagne 1988.

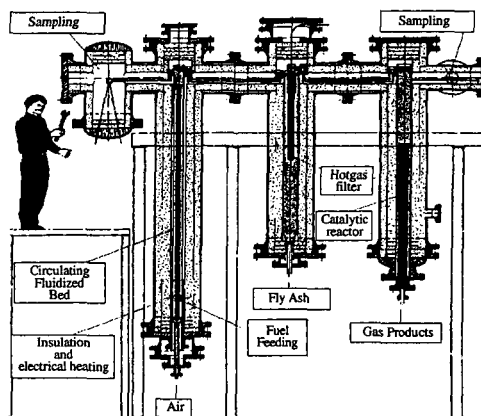


Figure 1. Schematic diagram of the LIT/PCFB gasifier

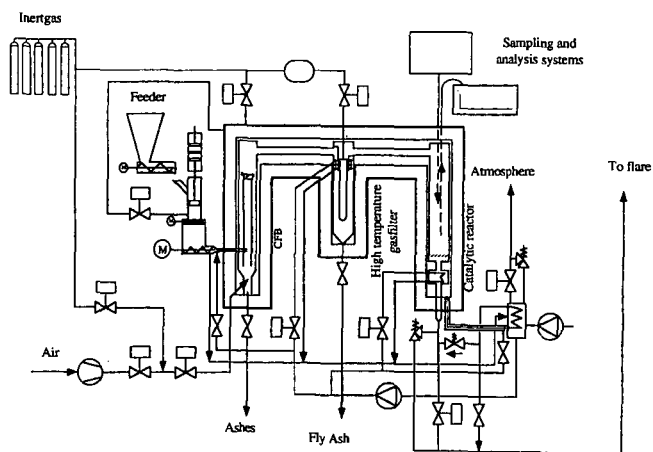


Figure 2. The process layout for the LIT/PCFB gasifier system

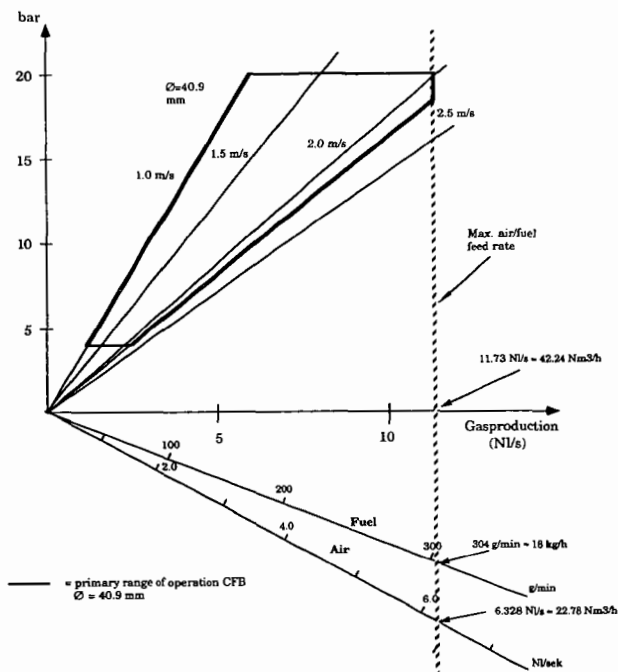


Figure 3. Test rig range of operation as a function of the fluidization velocity.

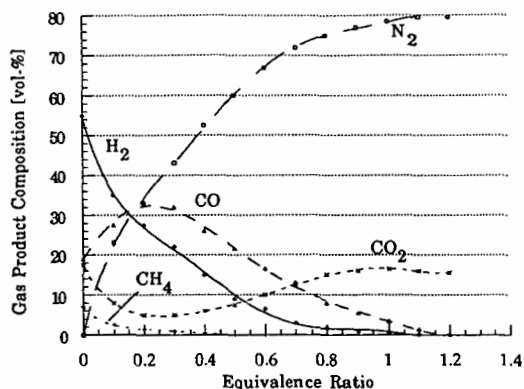


Figure 4. Gas product composition for adiabatic air/biomass conversion versus the air to fuel ratio at 0.1 MPa.